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CREEP AND STRESS-RUPTURE PROPERTIES OF AUSTENITIC  
CHROME - NICKEL STEELS IN PRESENCE OF SODIUM

By H.Böhm, H.Schneider

This assignment was carried out under the fast reactor association between the European Atomic Community and the Gesellschaft für Kernforschung, mbH, Karlsruhe.

A study was made on the influence of liquid sodium on the creep- and stress-rupture properties of two austenitic steels at 700°C. The tests were carried out on sodium filled tubes (X8CrNiMoV Nb 1613 and NiCr 3020) under uniaxial stress.

It is shown that the secondary creep rate of both alloys is not influenced by sodium whereas the tertiary creep stage is shortened, resulting in a reduction of fracture strain. Ni Cr 3020 time-to-rupture is decreased by the sodium. → p 2

Introduction

The creep and stress-rupture behavior of heat resistant materials exposed to sodium is gaining importance with the increasing use of sodium as a reactor coolant and the concomitant increase in coolant temperature. Experience has shown that knowledge of the corrosion behavior of a material in the relevant molten metal is an inadequate basis for deductions as to influence on stress-rupture properties. For instance, a number of metals and alloys are known to exhibit marked embrittlement in the presence of liquid metals (1)

Andrews et al (2) have reported on the influence of sodium flowing at approx. 1.35 cm/sec. on the

creep- and stress-rupture properties of a ferritic CrMo steel and of a 316 austenitic steel (corresponding to X5CrNiMo1810) at 600° and 650° C. These tests were carried out on 1.6 mm-thick plate specimens. They indicated that the time-to-rupture of the ferritic steel was slightly shorter in the presence of sodium, without revealing any dependence on sodium oxygen content (30 and 300 ppm). The creep strength of the austenitic steel did not change in sodium. The secondary creep rate and fracture strain of both alloys increased slightly in sodium.

The piece of research reported here was concerned with the influence of sodium on the creep and stress-rupture properties of X8CrNiMoVN1613 steel (Material No. 4988) in wall thicknesses which are possible for fuel element clad tubes. This steel is considered to be the most promising cladding material for a sodium-cooled fast breeder.

The purpose of the investigations into specimens of Incoloy 800 (NiCr3020) (material number 4861) was to identify the influence of a larger nickel content (resistance to sodium corrosion declines with increasing nickel content).

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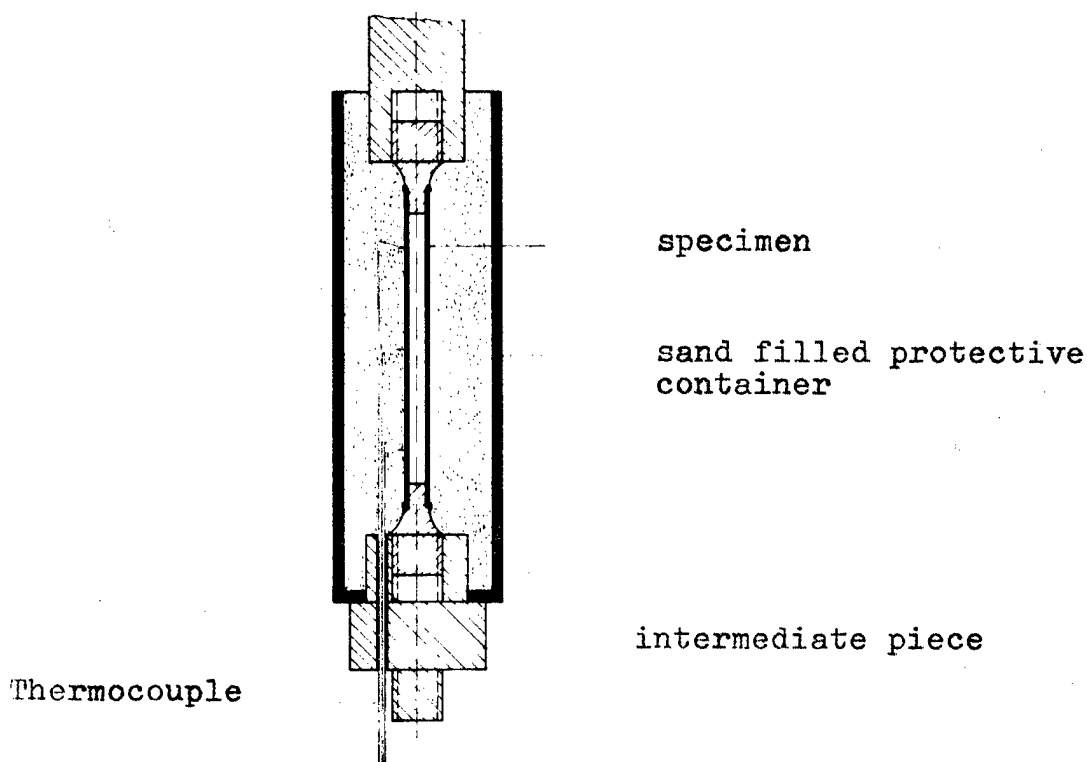
### Conduct of tests

Creep tests in flowing sodium involve considerable experimental outlay, so it was natural to begin by studying sodium influence in a static test. The tests were carried out on sodium-filled tubes measuring 110 x 7 x 0.4 mm under uniaxial stress at 700° ( $\pm 3^\circ$ ), in normal creep facilities (constructed by Mohr and Federhaff). The composition of the test alloys is given in Table 1.

Table 1  
Composition of alloys studied  
(weight %)

Material	X8CrNiMoVNb 1613	Incoloy 800
C . . . . .	0,07	0,016
Si . . . . .	0,40	0,60
Mn . . . . .	1,22	1,35
P . . . . .	0,018	0,01
S . . . . .	0,007	0,006
Cr . . . . .	17,10	20,6
Ni . . . . .	13,61	31,9
Mo . . . . .	1,30	-
V . . . . .	0,70	-
Nb/Ta . . . .	0,85	-

Fig. 1 . Facility for stress-rupture  
tests on sodium-filled tubes



Cleaned tube sections were first welded at one end to a 18/8-CrNi steel screw cap on an electron-beam welding facility. There were then filled under argon with sodium in a specially constructed apparatus, the sodium being sucked through a frit to minimise oxygen content. So sodium oxygen content was probably below 50 ppm. After it had been filled, the tube was welded to the second screw cap.

The test facility is depicted in Figure 1.

As protection against sodium escaping from a fracture, the tube was enclosed in a sand-filled protective container made of heat-resistant steel. Strain was measured during the test by a gage on the clamping head, after comparative measurements accuracy was completely adequate.

Parallel with tests on sodium-filled specimens, comparative tests were made on empty tubes in the same facility.

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### Test results

The influence of sodium on time-to-rupture, secondary creep rate and fracture strain was ascertained during the research. Test results are given in the following diagrams.

Figures 2 and 3 are stress-rupture diagrams for the two alloys, at 700°, with and without sodium. Sodium induces no marked change in the time-to-rupture of 16/13 CrNi steel; but the creep strength of Incoloy 800 is markedly reduced, the influence increasing with time (i.e. stress duration) and thus suggesting that a diffusion-controlled phenomenon is to blame.

Figure 4 shows the secondary creep rate of specimens of both alloys as a function of stress. It can be seen that all values lie

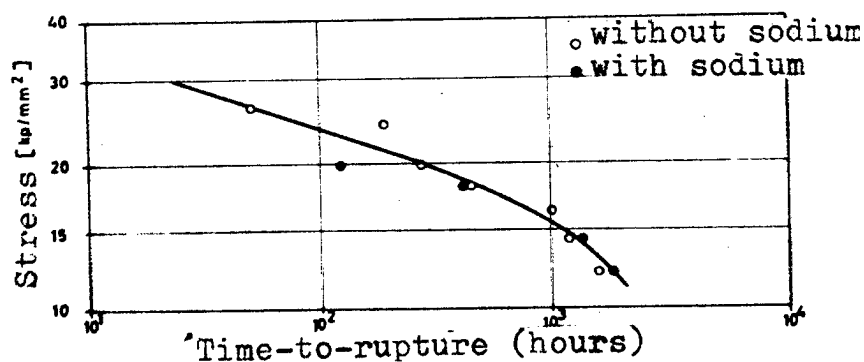


Fig.2 Stress-rupture diagram of X8CrNiMoVNb1613 steel at 700°C

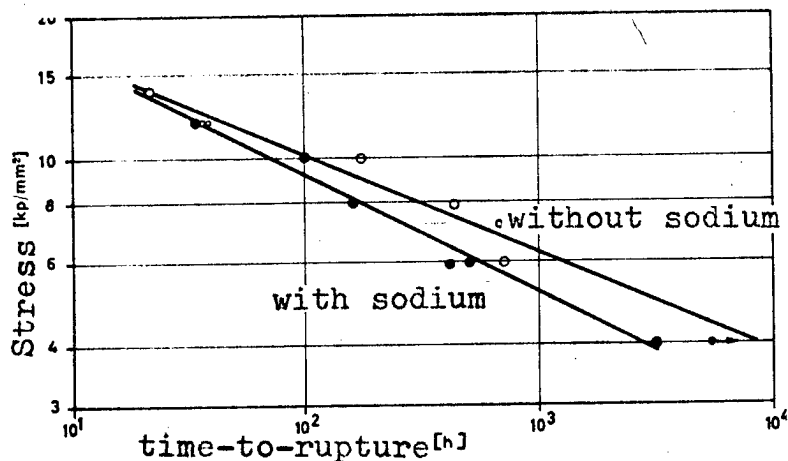


Fig.3 Stress-rupture diagram of Incoloy 800 at 700°C, with and without sodium

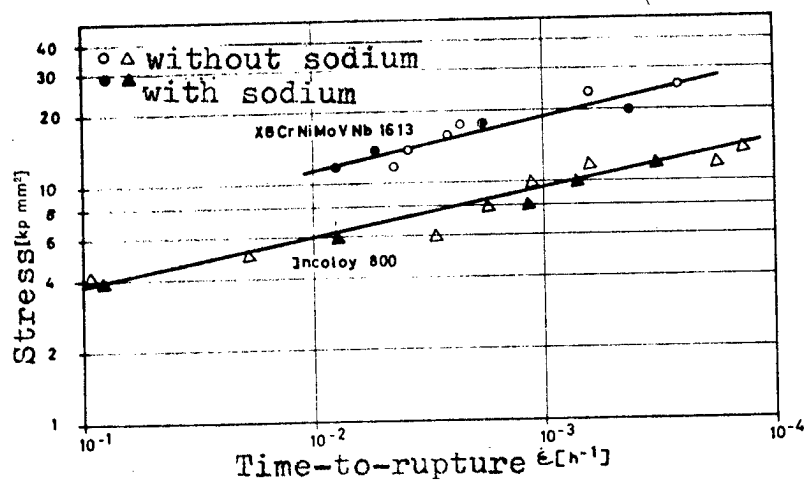


Fig.4 Secondary creep rate of Incoloy 800 and X8CrNiMoVNb1613 as a function of stress at 700°C

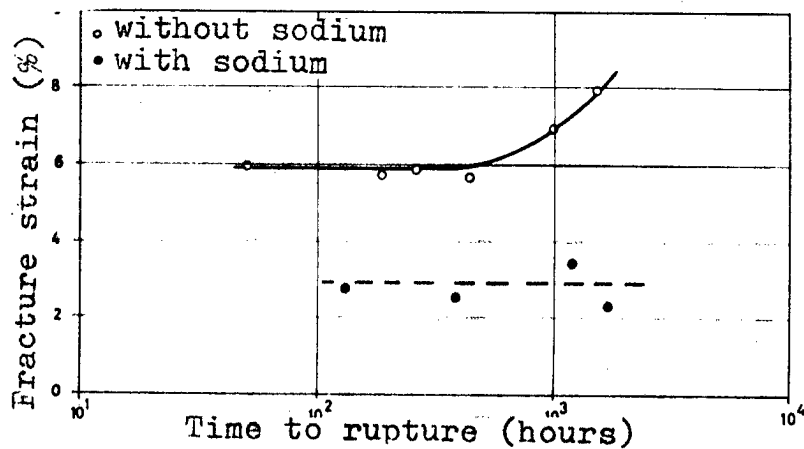


Fig. 5 Fracture strain of X8CrNiMoV Nb1613 steel in stress-rupture test at 700°C, with and without sodium.

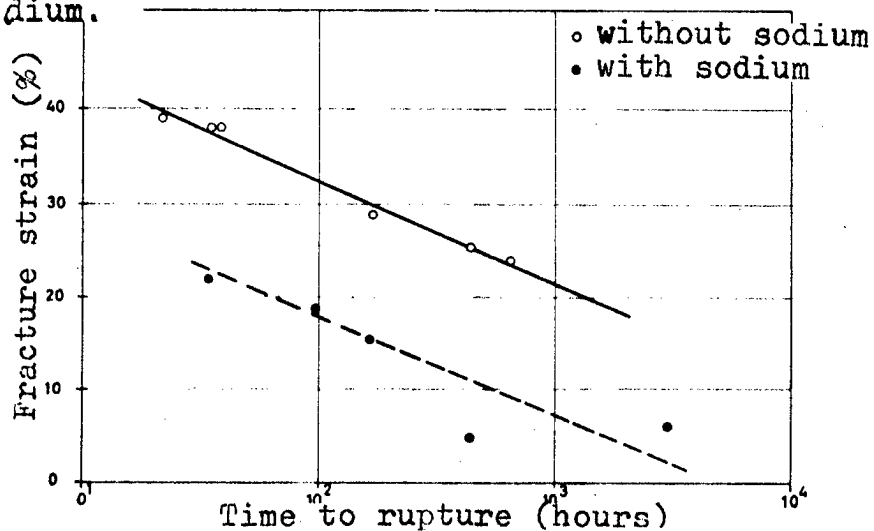


Fig. 6 Fracture strain of Incoloy 800 alloy in stress-rupture test at 700°C, with and without sodium.

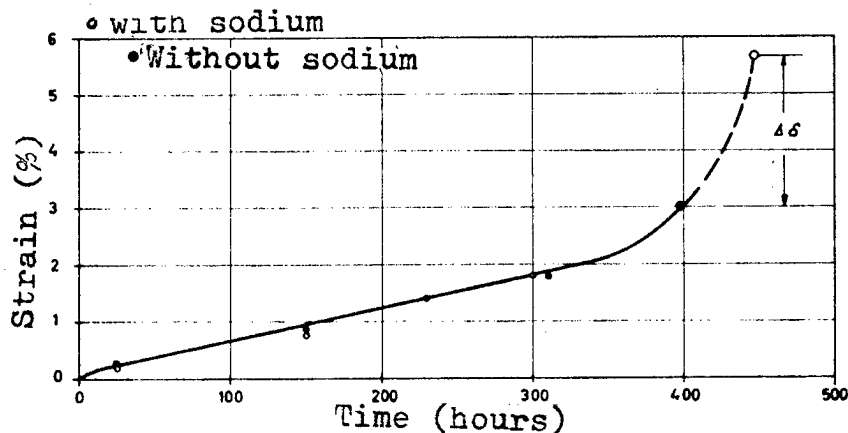


Fig. 7 Creep curves of X8CrNiMoV Nb1613 steel (16 kp/mm², 700°C)

within the normal scatter span, so that a clear sodium influence on secondary creep rate can be recognized.

The linear correlation between creep rate and time-to-rupture (double log plotting) shows that the stress-dependence of creep rate is satisfactorily described in both cases by the equation

The stress exponent  $m$  results from Fig. 4 for X8CrNiMoVNb1613 as 4.5, for Incoloy 800 as 5. These figures agree well with the theoretically calculated one (4).

$$\dot{\epsilon} = K\sigma^m$$

Creep strength and rate are only slightly or not at all affected by sodium. But the fracture strain of both alloys drops markedly in the presence of sodium, as witness Figures 5 and 6. The fracture strain versus time-to-rupture curve is very similar for sodium-free and sodium-filled specimens.

It is clear that only the tertiary creep stage of 16/13 CrNi steel is affected, in that fracture occurs very soon after this stage is attained while specimens not exposed to sodium experience considerable tertiary strain. Figure 7 illustrates this behavior by the 18 kp/mm<sup>2</sup> creep curves, which show exactly the same secondary creep rate for specimens with and without sodium.

The tertiary stage is brief in comparison with total time-to-rupture, indeed it is mostly shorter than the relatively broad scatter of the latter. This explains why fracture strain is sharply reduced but time-to-rupture unaffected by a shortening of the tertiary stage.



As with X8CrNiMoVNb1613, measured values show that the Incoloy 800 tertiary stage is markedly reduced by sodium; in addition, the tertiary stage begins earlier in the presence of sodium, and as a result, the time to rupture is markedly shortened.

To permit statements about fracture behavior, the fracture zones of creep specimens were inspected metallographically. Figures 8 a-h depict the fracture-zone structures of Incoloy 800 specimens which had been tested in air and in sodium at various stresses.

The "normal specimens" show numerous intercrystalline cracks scattered evenly across the cross-sectional area; Their number and size drops, as expected, with increasing load (i.e. increasing strain rate).

The inside of specimens tested in sodium are free from intercrystalline cracks; a few are merely found in the surface in contact with sodium.

The X8CrNiMo1613 specimens behave very similarly.

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#### Discussion of test results

The above results make it clear that sodium affects cracking and fracture phenomena in the tertiary creep stage, while secondary creep rate is mostly not changed to an extent exceeding normal scatter. Basically, only the tertiary stage of austenitic X8CrNiMoVNb1613 steel is shortened so that this stage begins at the same time; so it is fair to assume that sodium does not favor crack inception so much as crack propagation. The earlier beginning of the tertiary stage in Incoloy 800 caused by sodium suggests that crack formation is influenced here as well, probably because of enhanced corrosion though it may also be intercrystalline. -78.2

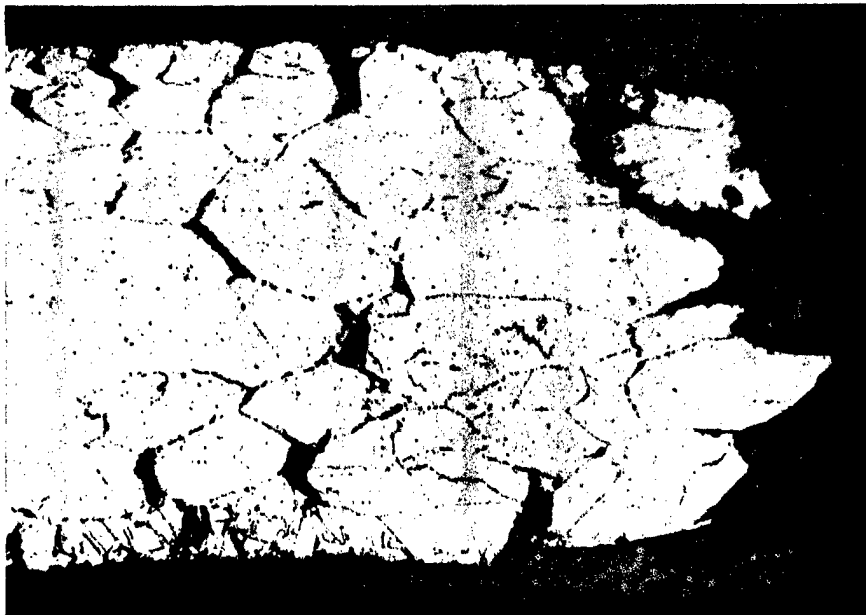


8 (a)



8 (b)

Fig.8 Fracture-zone structure of Incoloy-800 tube creep specimens. Test temperature 700°C.  
Specimens a,c,e and g; without sodium.  
Specimens b,d,f and h; in presence of sodium.  
Specimens a + b:  
 $\sigma = 6 \text{ kp/mm}^2$ , c+d: $\sigma = 8 \text{ kp/mm}^2$ , e+f: $\sigma = 10 \text{ kp/mm}^2$   
g+h: $\sigma = 12 \text{ kp/mm}^2 \times 200$



8 (c)



8 (d)

9a

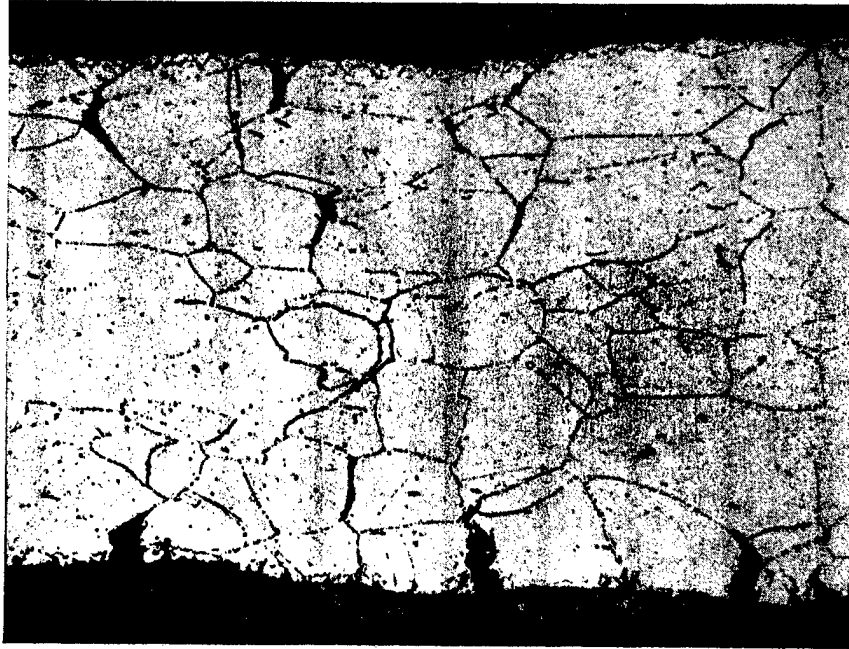


8 (e)



8 (f)

9h



8 (g)



8 (h)

The crack propagation change in both alloys is especially clear in pictures of specimen fracture-zone structures. To begin with, the absence of large intercrystalline cracks inside "sodium specimens" shows that these cracks only reach the size found in normal specimens very late in the tertiary stage.

Of special importance is the deduction from the absence of cracks that the smallest cracks beginning at the surface induce fracture quickly in the presence of sodium before internal cracks are discernible.

We are still not completely clear about the reasons for accelerated crack propagation in the presence of various liquid metals. Despite the common view (1) that embrittlement is due to a reduction in surface energy caused by absorption of atoms from liquid metal (thus reducing the amount of stress needed for crack growth), Stoloff and Johnston (5) attribute the drop in fracture strain and ductibility to a reduction in bonding strength at crack ends by chemically absorbed atoms.

The outcome of the research covered in this report differs considerably in several respects from results attained by Andrews et al (2). Here, our sodium-induced increase in secondary creep rate (over and above that in air) is doubtless less striking than the very different influence on fracture strain. We found a sharp reduction in fracture strain; Andrews and co-workers observed a fracture - strain increase in the presence of sodium.

There were major differences in the composition of the metals examined in the conduct of test and in other

important parameters such as specimen wall strength and deformation state as well as sodium temperature. So it is difficult to compare the results achieved in the two pieces of research, and further studies are needed to elucidate the reasons for the different behavior.

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### Abstract

The creep and stress-rupture properties of two austenitic steels were ascertained at 700° in the presence of sodium. The research involved a creep test on X8CrNiMoVNb1613 and NiCr 3020 tubes filled with sodium.

We observed no sodium influence on the secondary creep rates of the two metals. NiCr 3020 creep strength is reduced by sodium. The tertiary creep stage of the two alloys is shortened by sodium, and this leads to a marked reduction in fracture strain.

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